INFORMATION PROCESSING AS A FUNCTION OF PRESENTATION RATE

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Monterey, California

THESIS

INFORMATION PROCESSING
AS A FUNCTION OF PRESENTATION RATE

by

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September 1979

Thesis Advisor: D. E. Neil

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Information Processing As A Function of Presentation Rate		5. TYPE OF REPORT & PERIOD COVERED Master's Thesis September 1979
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Gunadi Gandhi Gan		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Postgraduate School Monterey, California 93940		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Postgraduate School Monterey, California 93940		12. REPORT DATE September 1979
		13. NUMBER OF PAGES 57
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) Naval Postgraduate School Monterey, California 93940		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Distribution unlimited; approved for public release

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Information Processing

Presentation Rate

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

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randomly presented visual stimuli were equally probable.

Performance, expressed as the rate of information transmission was observed (for twenty-three participants) in the key-pressing task on the RATER (Response Analysis Tester). By limiting the subject to only one response per stimulus, the number of correct responses was the rate of information transmitted. The results confirmed the hypothesis, i.e., the rates of information transmitted depended on the rate of information presentation ($p < .001$). The average information transmitted in the increasing presentation rate was significantly higher than in the decreasing presentation rates, irrespective of the sequence of presentation (Low High Low or High Low High).

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As A Function of Presentation Rate

by

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Major, Indonesian Navy

Submitted in partial fulfillment of the
requirement for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the

NAVAL POSTGRADUATE SCHOOL
September 1979

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An individual's information processing capability is a function of many variables - stimulus frequency, redundancy, stimulus clarity and practice. This thesis examines the effect of varying stimulus presentation rate; 1) from a low rate through a high rate and back to a low rate again and, 2) from a high rate through a low rate and back again to the high rate. The four randomly presented visual stimuli were equally probable.

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I. BACKGROUND

A. INFORMATION PROCESSING

It is convenient to view man as a system component whose primary purpose is information processing. Man receives information from his environment through various forms of physical energy such as light, pressure, sound, heat, etc. This environmental information is encoded by man's sense organs, processed and stored. The sensory organs tranduce the processed information into response or action such as postural adjustment of the body and limbs, search and scan movement of the eyes, production of speech, etc.

As a system component, the model of human information processing consists of four subsystems (Van Cott & Warrick, 1972): a) sensing, b) information processing, c) memory and storage and, d) responding. Information processing tasks are the mapping of a set of inputs into a set of outputs, independent of the energy transactions to carry it out (Sheridan & Ferrell, 1974). The emphasis on information is not to deny that energy is also involved; it is clear that energy must always be present to transmit information. It is merely to say that performance can be understood more completely in terms of the processing of information than in terms of the transformation of energy (Fitts & Posner, 1967).

Information processing tasks have been classified by Fitts & Posner (1967) into: a) transmission of information,

b) reduction of information, and c) elaboration of information. Since the transmission of information is the object of the present study, it is therefore appropriate to measure performance in terms of information transmitted. Experimental results and models in discrete information transmission tasks referred to by Sheridan & Ferrell (1974) and Crumbley, et al (1961) present the basic concept of man as a limited information channel. They postulate that finite stimuli with equal probabilities have the maximum rate of information transmission.

B. INFORMATION TRANSMISSION

As previously mentioned, one of the products of information processing is information transmission. To investigate further the characteristics of transmission, it is helpful to know something about human channel capacity, that is, to know the maximum amount of information that a human can transmit if all the variables known to influence processing are kept at a level where optimal transmission can occur. Generally, transmission is best when: a) the stimulus preception and discrimination are easy, b) the response is easily executed, c) stimulus and response are compatible, and d) the set of possible information categories at any given time is known.

To test whether or not the information transmission is at optimum, it is necessary to exclude the effect from the input and output sides, so that the transmission is mostly attributed to the central processor. Factors affecting the information

transmission include:

1) Parrallel processing:

There is evidence of man's capability to analyze more than one sensory input at a time (Cherry, 1976); consequently some fraction of total capacity must be devoted to keeping track of the parallel operation, which means that the transmission capacity is not fully used.

2) Redundancy:

Redundancy or the excess of information in stimuli could increase the discriminability of an input set (Sheridan & Ferrell, 1974), and hence should result in more information transmitted. Crumley et al (1961) suggested, as the speed requirement in a simple task was increased, increased redundancy would decrease error and increase the amount of information transmitted.

3) Task dimension:

Task dimensionality contributes to the information content of a set of stimuli. Capacity for transmitting information with multidimensional stimuli was greater than a unidimensional stimulus (Miller, 1956).

4) Absolute judgement:

Absolute judgement is applied when comparing a current observation with a remembered, internal version of the standard. A review of the literature by Miller (1956) indicated that the amount of information that man could transmit (the span of absolute judgement) was between 2.2 to 3.25 bits

in unidimensional visual stimuli having 4 to 11 alternatives and between 2.30 to 2.50 bits in unidimensional auditory stimuli having 5 to 7 alternatives. Total information transmitted for a two dimensional judgement was substantially higher than when either stimulus dimension was judged alone (Corso, 1967).

5) Input-Output processing:

Crumley et al (1961) stated that because of input-output limitations, man can process information only up to a certain rate, but under information overload conditions, he samples randomly.

6) Rehearsing and practice:

Rehearsing performance and practice could contribute to the increase in transmission capacity of central processing. The effect of practice or learning on the ability to judge unidimensional stimuli showed significant improvement in accuracy as well as in speed (Sheridan & Ferrell, 1974). Therefore, to measure only the capacity of central processing, information redundancy, task dimension, absolute judgement (number of alternatives), input-output processing and practice are to be controlled. Information redundancy and rehearsing/practice are usually controlled by excluding them from the test conditions.

C. INFORMATION

Early in communication theory, Weaver (1949) defined information as a measure of one's freedom of choice when one was

to select a message. If one was confronted with a very elementary situation in which he had to choose one of two alternative messages then the information associated with the above situation was unity. The concept of information here was applied to the situation as a whole (a set of alternatives) not to the content of the message, i.e., its meaning. The unit of information was the amount of freedom of choice one had in selecting a message and was called a bit (binary digit). In a simple situation where a choice was made only between several definite messages, the information source made a sequence of choices from some set of elementary symbols which then formed a message. As the symbols were chosen, these choices were governed by probabilities, which were not independent but at any state of the process depended upon the preceding choices. Weaver (1949) proposed that if a set of n independent messages whose long run probabilities are:

$$p_1 , p_2 , p_3 , \ldots\ldots , p_n$$

then the expression for the information content is:

$$H = - (p_1 \log_2 p_1 + p_2 \log_2 p_2 + \ldots\ldots + p_n \log_2 p_n)$$

Corso (1967) defined information as a result of acts of communication that reduce the uncertainty in the situation under consideration. Uncertainty is based upon lack of knowledge about the given situation; information provides for the reduction of uncertainty. In obtaining the measure of information, he further suggested considering not only the outcome

of the act that did occur, but also the complete set of outcomes that might have occurred. The amount of information is exactly the same as the uncertainty prior to the occurrence of the act. The maximum uncertainty will exist when the two alternatives have the same probability of occurrence. The choice between two alternatives, which on a-priori basis are equally likely, makes one unit of information or bit.

Let n be the number of equally likely alternatives, and H be units of information. Two equally likely alternatives convey one unit of information (one bit); it can be expressed as:

$$n = 2$$

$$n = 2^H \text{ , where } H = 1 \text{ bit}$$

Deriving from this relation, the sequence of the power of 2 is as follows:

$$2^0 , 2^1 , 2^2 , \ldots\ldots , 2^H$$

If prior knowledge in a situation reduces the set of possible outcomes to a single event, then there is no choice to be made and no information to be transmitted, as described in this relation:

$$1 = 2^H \text{ where } H = 0$$

Based upon two equally likely alternatives, logarithm of base 2 can be derived and be used as a function in computing the amount of information conveyed by the alternatives.

If $n=2^H$, then $\log n = H \log 2$. Applying log function of base 2, it gives:

$$\log_2 n = \log_2 2^H$$
$$= H \log_2 2$$
$$= H$$

So, the expression of the amount of information can be written as: $H = \log_2 n$

Therefore, the amount of information in bits (H) is a log function of the number of alternatives. Since the alternatives have equally likely probability of occurrence and let p_i be the probability of i^{th} alternative to occur then:

$$p_i = \frac{1}{n}$$
$$H = \log_2 n = \log_2 \frac{1}{p_i}$$
$$= \log_2 1 - \log_2 p_i$$
$$= -\log_2 p_i$$

If $n = 4$, then $p_i = \frac{1}{4}$, and will convey information $H = \log_2 4 = 2$ bits. Therefore:

- 4 alternatives convey 2 bits
- 4 alternatives have equal probability of occurrence

Thus, in this situation each alternative conveys .5 bit of information. Applying a logarithmic function to each alternative in terms of its associated probability, it is obtained:

$$-\log_2 p_i = -\log_2 \frac{1}{4} = 2$$
$$-p_i \log_2 p_i = -\left(\frac{1}{4} \log_2 \frac{1}{4}\right) = -\frac{1}{4}(-2) = .5$$

To generalize,

$$H = \log_2 n = -\sum_i p_i \log_2 p_i \quad ; \; i = 1,2...n$$

H is computed here as the average of uncertainty; the expected value of the probability of alternative p_i taking values at discrete logarithmic probability function (p log p).

Therefore, as previously suggested, the amount of information conveyed by the alternatives is defined as:

$$H = -\sum_i p_i \log_2 p_i$$

D. INFORMATION TRANSMITTED

In the simple case, Sheridan & Ferrell (1974) discussed the average information transmitted through a channel for each message sent. Assuming communication or processing of information from a set of stimuli to a set of responses, the amount of information transmitted can be described as the statistical association of stimulus and response. The relation of the information processing is shown by the following Venn diagram:

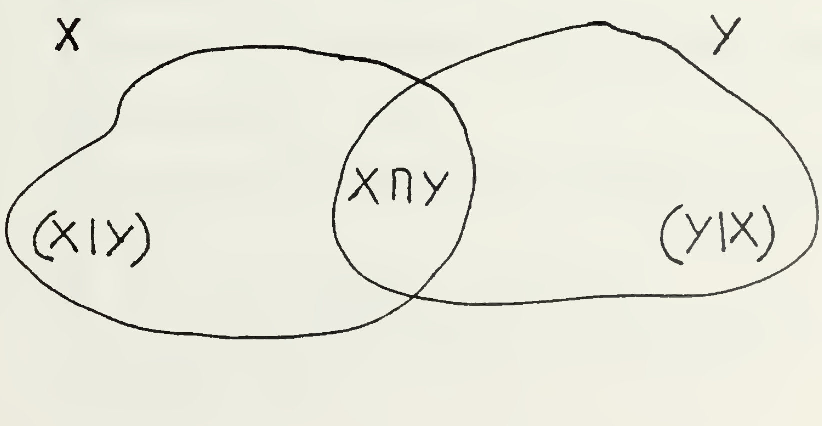

FIG. 1. VENN DIAGRAM OF INFORMATION RELATION

X: the set of stimuli

Y: the set of responses

$X \cap Y$: the information transmitted

In set relation, it can be expressed as follows:

$$(X \cup Y) = (X) + (Y) - (X \cap Y)$$

$$(X \cap Y) = (X) + (Y) - (X \cup Y)$$

Hence the probability expression is written as:

$$P (X \cap Y) = P (X) + P (Y) - P (X \cup Y)$$

Then, the expected value or the average is obtained as:

$$\begin{aligned} E (X \cap Y) &= E (X) + E (Y) - E (X \cup Y) \\ &= \sum_i f(x_i)\, p(x_i) + \sum_j f(y_j)\, p(y_j) \\ &\quad - \sum_i \sum_j f(x_i, y_j)\, p(x_i, y_j) \end{aligned}$$

where $f(x_i)$ is the logarithmic function of alternatives and E (X Y) is the average amount of uncertainty in the intersection set X Y. E (X Y) is usually written as T (X,Y).

Therefore,

$$\begin{aligned} T(X,Y) &= \sum_i \log_2 \frac{1}{p(x_i)} \cdot p(x_i) + \sum_j \log_2 \frac{1}{p(y_j)} \cdot p(y_j) \\ &\quad - \sum_i \sum_j \log_2 \frac{1}{p(x_i, y_j)} \cdot p(x_i, y_j). \end{aligned}$$

$$H (X) = \sum_i \log_2 \frac{1}{p(x_i)} \cdot p(x_i)$$

(the average uncertainty of stimulus set)

$$H (Y) = \sum_j \log_2 \frac{1}{p(x_j)} \; p(x_j)$$

(the average information conveyed by the response set)

$$H(X,Y) = \sum_i \sum_j \log_2 \frac{1}{p(x_i, y_j)} \; p(x_i, y_j)$$

(the information content of stimulus - response set)

The above average amount of uncertainty can then be written as:

$$T(X,Y) = H(X) + H(Y) - H(X,Y)$$

The conditional uncertainty is obtained from the following (Clark & Disney, 1970):

$$(X) = (X \cap Y) + (X \cup \bar{Y})$$

$$(X \cap \bar{Y}) = (X) - (X \cap Y)$$

$$P(X) = P(X \cap Y) + P(X \cap \bar{Y})$$

$$P(X \cap \bar{Y}) = P(X) - P(X \cap Y)$$

$$P(X/Y) = P(X) - P(X \cap Y)$$

$$E(X/Y) = E(X) - E(X \cap Y)$$

Since $E(X/Y)=H(X)$, $E(X)=H(X)$ and $E(X \quad Y)=T(X,Y)$ then,

$$H(X/Y) = H(X) - T(X,Y)$$

also

$$H(Y/X) = H(Y) - T(X,Y)$$

As described by Sheridan & Ferrell (1974), in any act of communication there might occur:

1) Equivocation: The amount of information about the stimulus set X that might have been transmitted but was not, and it is written as $H(X/Y) = H(X) - T(X,Y)$; i.e., when several different stimuli tend to result in a single response. Figure 2 is an example of equivocation. The subject didn't distinguish the second stimulus as different from the first. This results in the loss of information that would have been contributed by the stimulus, so the transmission is only 1.5 bits instead of 2.0 bits and the equivocation is 0.5 bits,

Stimulus X_i \ Response Y_j	1	2	3	4	probability of stimulus
1	.25				.25
2	.25				.25
3			.25		.25
4				.25	.25
probability of response	.50	0	.25	.25	1.00

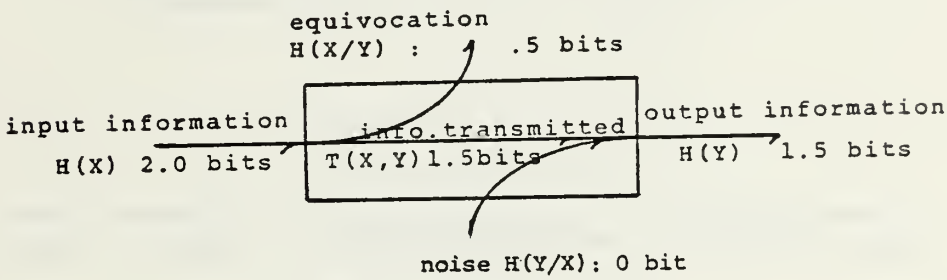

FIG. 2. TRANSMISSION WHICH HAS ONLY EQUIVOCATION

2) Noise: The amount of information in the response set which does not correspond to information in the stimulus set, and it is written as $H(Y/X) = H(Y) - T(X,Y)$; i.e., when the same stimulus leads to different response on different occasions. Figure 3 is an example of noise. The subject, presented with stimulus #1 responded as if stimuli #1 and #2 had been presented. This additional response can be considered as noise,

Stimulus X_i	Response Y_j 1	2	3	4	probability of stimulus
1	.25	.25			.50
2					0
3			.25		.25
4				.25	.25
probability of response	.25	.25	.25	.25	1.00

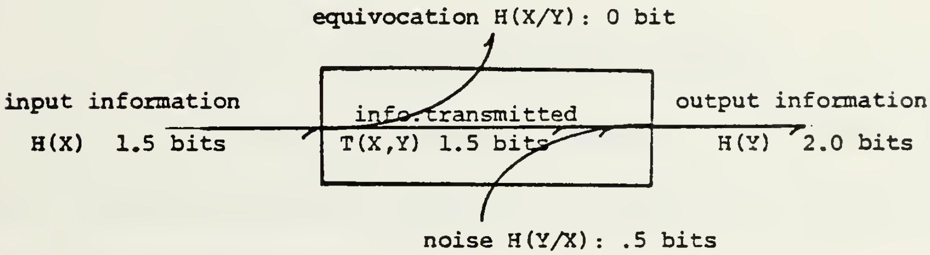

FIG. 3. TRANSMISSION WHICH HAS ONLY NOISE

or 3) equivocation and noise, i.e., when there is a tendency of a single stimulus to give rise to different responses and a single response to result from several stimuli. Figure 4 is an example of equivocation and noise.

Stimulus X_i	Response Y_j 1	2	3	4	probability of stimulus
1	.20	.04		.01	.25
2	.02	.18	.05		.25
3	.02	.04	.16	.03	.25
4			.03	.22	.25
probability of response	.24	.26	.24	.26	1.00

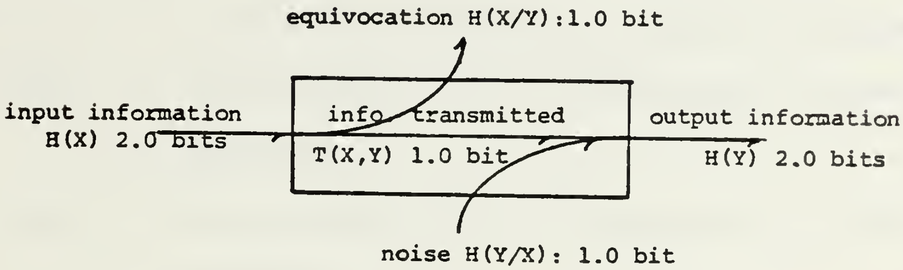

FIG. 4. EQUIVOCATION & NOISE

The model proposed by Shannon & Weaver (1949) as the basis of a computational formula to obtain the amount of information transmitted was,

$$T(X,Y) = H(X) + H(Y) - H(X,Y)$$

As mentioned by Kodalen (1975), the model assumed the following:

1) The number of stimuli and response governing the activities under consideration was limited.
2) The number of times each response occurs to each stimulus could be obtained.
3) The probabilities governing the events were known and not changing.

Computation of information transmitted as discussed by Corso (1967), Fitts & Posner (1967) and Warrick & Van Cott (1972) always has these two requirements:

1) It is necessary to obtain a data matrix consisting of stimulus (S) categories and response (R) categories. The cells of the matrix contain the frequencies with which a particular stimulus produces a particular response. From the S-R data matric the following can be determined:

$p(j,k)$: the probability of the joing occurrence of a particular stimulus k and a response j

$p(j)$: the probability of occurrence of each response j

$p(k)$: the probability of occurrence of each stimulus k

$p_k(j)$: the conditional probability of response j given stimulus k

$p_j(k)$: the conditional probability of stimulus k having occurred, given response j

2) No failure of performance, i.e., for each stimulus there must exist a response.

Crumley et al (1961) postulated that as information challenge (stimulus presentation rate) increased, errors became increasingly frequent; finally leading to the breakdown of transmission which he called the confusion effect. When communication broke down, as indicated by more than one response per stimulus or failure to respond, the conditions assumed by Shannon & Weaver (1949) could no longer be met due to the following reasons:

1) there is more than one response per stimulus

2) the subjective probabilities governing the event are changing.

Thus the Stimulus - Response matrix cannot be developed. Therefore, another method to compute the amount of information transmitted was suggested. McCormick (1976) suggested that human responses can be viewed as conveying information; indeed this was evident in instances in which the outputs were intended to correspond with input stimuli. The efficiency with which man can transmit information through his responses depends upon the type of information input and the type of responses required.

McCormick's approach was utilized by Alluisi, Muller & Fitts (1957), who found that the maximum information processing rate for verbal responses was higher than the motor (key - pressing) responses, 7.9 bits per second and 2.8 bits per second respectively. The amount of information transmitted in verbal and motor responses of a forced - paced serial task was a function of the number of alternative stimuli, the rate of stimulus presentation and the joint effect of number of alternatives and the rate of stimulus presentation (the rate of information presentation). Therefore, if the number of alternative stimuli is kept constant, the amount of information transmitted will vary according to the rate of stimulus presentation.

Cumming & Croft (1973) conducted an experiment on the rate of human information transmission in which four subjects

performed a key-pressing task in response to random digits presented binaurally via earphones. The digit presentation rate was gradually increased from a low rate to a higher rate and then decreased again to form a symmetric cycle. The results showed that the relationship between performance and demand depended upon the time history of demand. Specifically they found:

1) that as demand increased, performance rose to a level, beyond which overload occurred and performance deteriorated.
2) as demand decreased, the peak achieved under increasing demand was not reached again; instead performance remained constant until considerable reduction in demand had occurred, as shown in Figure 5.

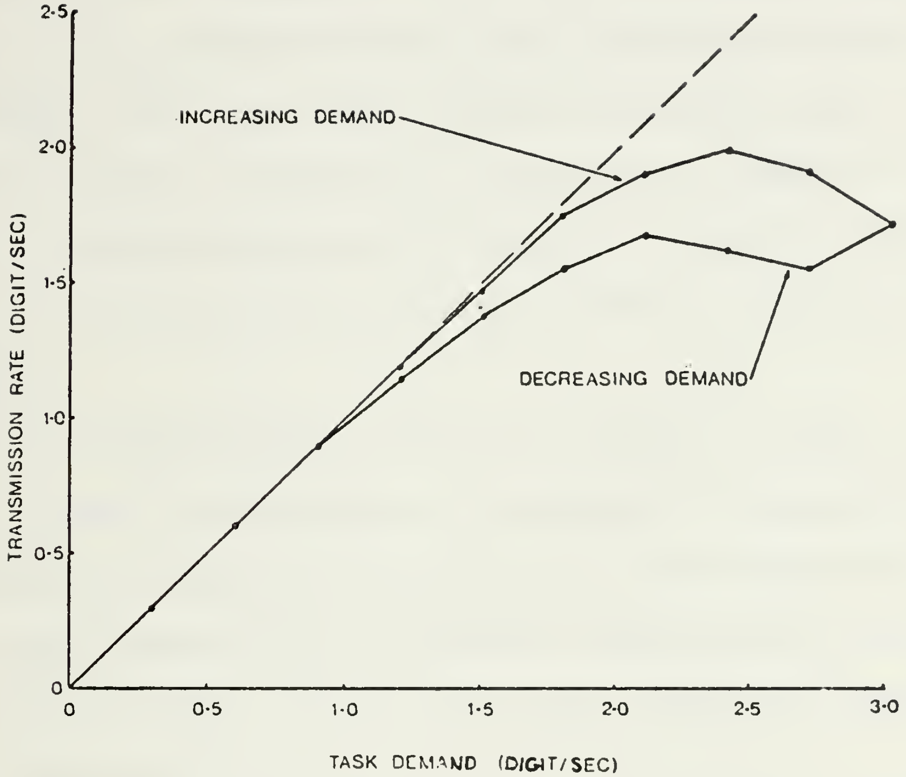

FIG. 5 : VARIATION OF PERFORMANCE (after Cumming & Croft, 1973)

E. PURPOSE OF THIS EXPERIMENT

The purpose of present study was to investigate human information processing, using the model of Cumming & Croft (1973). While Cumming & Croft (1973) used only a low to high to low presentation rate with auditory stimuli, this experiment will use visual stimuli presented under two different stimulus presentation conditions: Condition #1 the rate of presentation varied from low to high to low and Condition #2 the rate of presentation varied from high to low to high.

It was hypothesized, based on Cumming & Croft (1973), that 1) peak of performance in information transmission achieved for increasing presentation rates would be higher than that achieved for decreasing presentation rates; 2) the general shape of the curve would remain the same under both conditions.

In order to test the hypotheses, the RATER (Response Analysis Tester) was employed to assess subject's information processing capability. The RATER has been used in experiments by the U. S. NAVY to compare adjectival and non-adjectival rating scale (Helm, 1974) and by NASA (National Aeronautic and Space Administration) to study performance in a revolving space system simulator (Newsom, Brady & O'Laughlin, 1966).

II. METHOD

A. STIMULI

There were four geometric symbols used as stimuli, viz. circle (○), cross (+), triangle (△) and diamond (◇). The stimuli were presented randomly.

B. APPARATUS

The RATER (Response Analysis Tester) Model 3, built by General Dynamic Convair Division, is designed to provide sensitive, reliable measurement of response speed, accuracy and short term memory. The device shown in Figure 6 consists of an experimenter console and subject response unit.

The experimenter console shown on the right contains counters and switches. The three counters record the number of presentations, the number of total responses and the number of correct responses. The switches control the following functions:

1. Power: on/off
2. Self pace/Auto pace

   Self pace: subject control his own response rate

   Auto pace: experimenter controls the presentation rate
3. Ready/test on

   Ready: ready for experiment

   Test on: test in progress

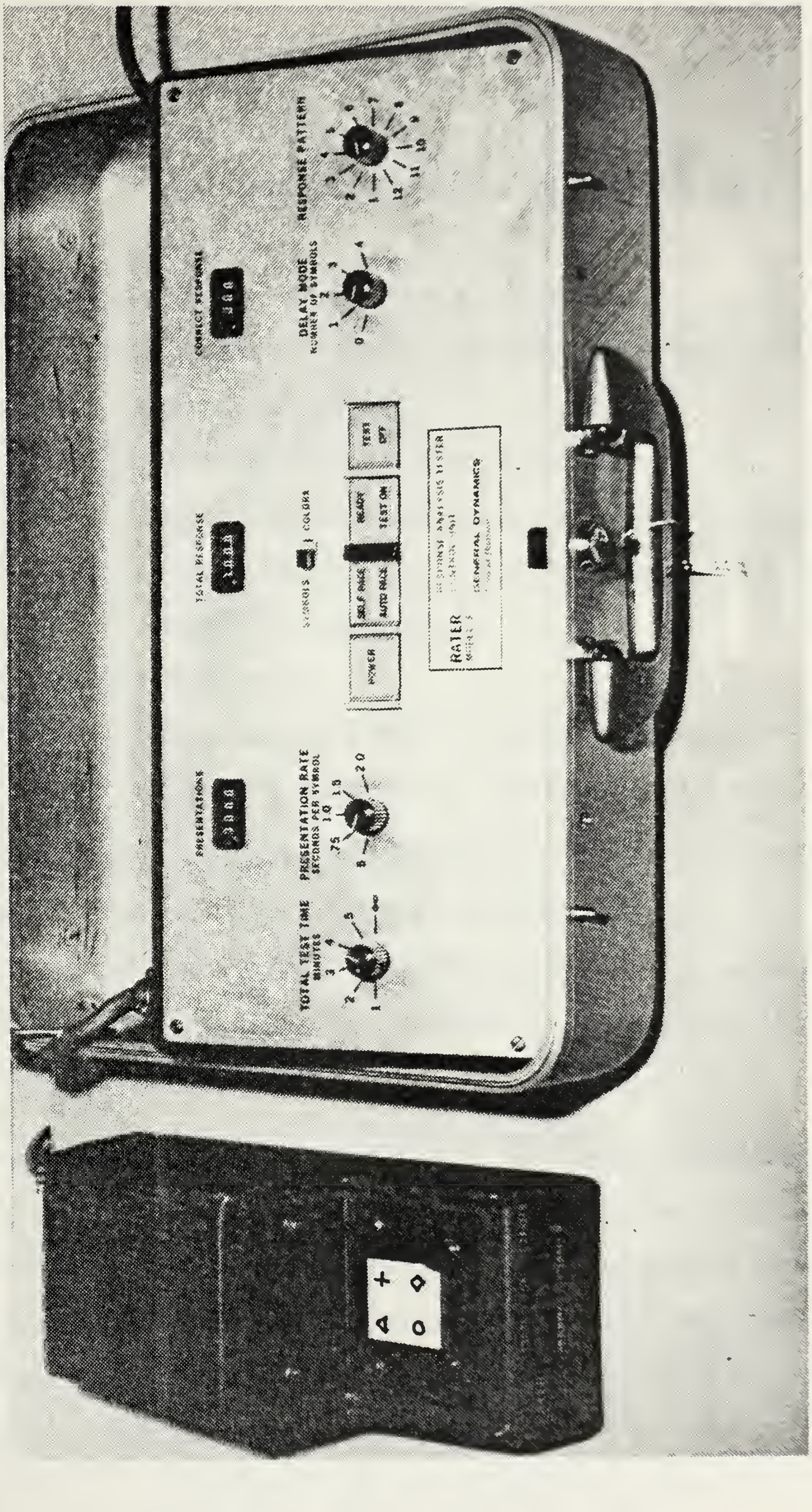
TOTAL TEST TIME
MINUTES
PRESENTATIONS
PRESENTATION RATE
SECONDS PER SYMBOL
TOTAL RESPONSE
CORRECT RESPONSE
DELAY MODE
NUMBER OF SYMBOLS
RESPONSE PATTERN
POWER
SELF PACE
AUTO PACE
READY
TEST ON
TEST OFF
SYMBOLS
COLORS
RATER
GENERAL DYNAMICS

FIG. 6 RATER

4. Test Off

5. Total Test Time (in minutes)

   Total test duration (in minutes) from 1 to infinity.

6. Presentation rate (second per symbol)

   The rate is from 2 seconds per symbol to .5 second per symbol.

7. Delay mode (number of symbols)

   The number of symbols (0,1.2.3.4,) the subject is required to delay his response after the symbol is presented.

8. Response pattern

   The relative position of correct response can be varied through 12 different positions.

The subject response unit shown on the left contains a display window and four response buttons. A card (see Fig. 6) indicating the correct response pattern was placed on the response button panel so as to maximize the ease of the task.

C. SUBJECTS

Twenty-three students of the U. S. Naval Postgraduate School participated in this experiment. Subjects ranged in age from 28 years to 39 years with no known mental or physical disorders. All subjects showed alertness and eagerness to participate in the experiments. Subjects were not paid and participation was strictly voluntary.

D. DESIGN

Performance on the RATER was selected as a measure of performance in information transmission tasks. It was assumed that:

1) Subject's responses were completely determined by presentation rate and total task duration.
2) The occurrences of successive stimuli did not alter the subject's knowledge of the statistical properties of the stimulus set as a whole.
3) Subject's average uncertainty per stimulus presentation remains constant throughout each presentation rate.
4) Subjects were familiar with the task.

The experimental design meets the above assumptions by:

1) presenting the stimuli randomly,
2) informing the subjects of the probability of the stimulus occurrence, stimulus categories and/or response categories,
3) providing preliminary practice on a series of similar patterns and presentation rates which will serve as a baseline for measurement.
4) allowing the subject to make only one response to each stimulus.

The basic task of the RATER consists of four Stimulus-Response alternatives, requiring $H=3.329 \times \log 4 = 2.0$ bits of information for successfull completion. In the auto-paced

condition, although each task still has a constant information of 2.0 bits, the difficulty of the task can be varied by increasing the presentation rate (Long & Fishburne, 1973). The independent variables were; 1) the rate of stimulus presentation and; 2) task duration. The dependent variable was the number of correct responses.

There were two presentation rate conditions. Condition #1 consisted of presentation rates started from the lowest presentation rate (2 seconds per symbol) to the highest (0.5 second per symbol) then back to the lowest presentation rate. Condition #2 consisted of a set of presentation rates started from the highest (0.5 second per symbol) to the lowest (2 seconds per symbol) then back to the highest presentation rate. Only one condition was assigned to each subject. The assignment of each condition was determined by the toss of a coin. Whenever the coin showed heads condition #1 was assigned; otherwise condition #2 was assigned.

E. PROCEDURE

Prior to the experiment, a pilot study was conducted to validate the instructions, determine the feasibility of the experiment and ensure that all the equipment worked properly. It also enabled the experimenter to master the routine of the experiment.

The experiment was conducted at the Man Machine System Design Laboratory of the Naval Postgraduate School, in an environmental chamber, where outside noise and incidental

lighting that might disturb were controlled. Subjects were briefed on the equipment to be employed and a brief explanation of what was meant by information processing was given (see Appendix A).

Each subject was given one minute of practice with a presentation rate of 1 second/symbol, followed by a break period. During the break, any questions the subject had regarding the task he was to perform were addressed and the rate of stimulus presentation was changed. The subject then performed the task during one minute of practice with another presentation rate of .75 second/symbol. Task configuration of the practice session was as follows:

1. Manual start and automatic stop of test session.
2. Length of practice session: 2 minutes
3. Type of stimulus presented at display on subject's console: cross (+), circle (○), triangle (△), diamond (◇).
4. Pace of trials: auto-paced; constant rate of stimulus presentation maintained.
5. Rate of stimulus presentation: a) 1.0 second/symbol
b) .75 second/symbol
6. Delay: 0; subject was to respond to the current stimulus at the display.
7. Stimulus-response button relationship: as shown in Figure 6.

The practice session was followed by a rest period. A coin was flipped to determine the condition to be assigned. The test session began after setting up the equipment according to the condition assigned.

There were two test sessions. Each test session consisted of 9 one minute trials and 8 fifteen second rest periods for a total of eleven minutes. The rest period between sessions was about 5 minutes, during which the subject was allowed to leave the chamber. The task configuration of the test session was as follows:

1. Manual start and automatic stop of test session.
2. Length of test session: 11 minutes

   Total test time: 9 minutes

   Total rest period: 2 minutes
3. Type of stimulus presented at display on subject's console: cross (+), circle (○), triangle (△), diamond (◇).
4. Pace of trials: auto-paced; constant rate of stimulus presentation.
5. Rate of stimulus presentation:

   Condition #1 (low high low)
   Condition #2 (high low high)

   Low-high-low (sec./symbol): 2, 1.5, 1, .75, .5, .75, 1, 1.5, 2.

   High-low-high (sec./symbol): .5, .75, 1, 1.5, 2, 1.5, 1, .75, .5.

6. Delay: 0; subject was to respond to the current stimulus in the display.

7. Stimulus-response button relationship: As shown in Figure 6.

F. REDUCTION OF DATA

At the conclusion of the experiment, there were 23 data sheets. Each sheet contained two sets of data from the practice session and eighteen sets of data from the test sessions. The data recorded were the total presentation (TP), total responses (TR) and the correct responses (CR).

The data obtained in the test sessions were analyzed and screened by the following procedures:

a) Failure to comply with instructions:

One participant failed to comply with the instructions during the test session. Therefore, his data were discarded.

b) Mechanical difficulty:

Two data sheets showed mechanical difficulties in which it was found that the TR (total response) was less than the CR (correct response). These data were also discarded.

c) Commission error:

The TR (total response) that exceeded the TP (total presentation) was considered as commission error (Long & Fishburne, 1973). The commission error was then subtracted from the CR (correct response).

d) Average of correct responses:

The number of correct responses in each presentation rate were averaged and reduced to 9 values per subject (see Appendix B).

G. ANALYSIS OF DATA

Values for subject's correct response were transformed into information transmission rates. For example, the correct response obtained in one minute duration of a particular presentation rate is 40, then the transmission rate is 40/60 = .75 symbol/second. Since one symbol as a response conveys 2 bits, then .75 symbol/second conveys 1.50 bits/second. The transformation of presentation is shown on Table 1.

TABLE 1: TRANSFORMATION OF PRESENTATION RATES

second/symbol	symbol/second	bit/second
.50	2.00	4.00
.75	1.33	2.67
1.00	1.00	2.00
1.50	.66	1.33
2.00	.50	1.00

Tables 2a and 2b contain the transformation of the average correct responses. The average transmission rates were also plotted against the presentation rates.

TABLE 2a: MEAN INFORMATION TRANSMISSION RATES
UNDER LOW HIGH LOW CONDITION (SYMBOL/SEC. & BIT/SEC.)

SUBJECT	PRESENTATION RATE (SYMBOL/SECOND & BIT/SECOND)								
	.50	.66	1.00	1.33	2.00	1.33	1.00	.66	.50
	1.00	1.33	2.00	2.67	4.00	2.67	2.00	1.33	1.0
1	.4833 .9666	.6583 1.3166	.9333 1.8666	.8250 1.6600	.5000 1.0000	.8000 1.6000	.9083 1.8166	.6583 1.3166	.4833 .9666
2	.5000 1.0000	.6500 1.3000	.9083 1.8166	.8666 1.7332	.3833 .7666	.4833 .9666	.7916 1.5832	.6666 1.3332	.4833 .9666
3	.4416 .8832	.6666 1.3333	.8583 1.7166	.7166 1.4333	.3583 .7166	.5583 1.1166	.9333 1.8666	.6500 1.3000	.4833 .9666
4	.4750 .9500	.6500 1.3000	.9333 1.8666	1.0916 2.1932	.5083 1.0166	1.0666 2.1333	.9500 1.9000	.6416 1.2833	.4916 .9833
5	.4916 .9833	.6666 1.3333	.9750 1.9500	1.0916 2.1833	.5833 1.1666	.9833 1.9666	.9666 1.9333	.6666 1.3333	.5000 1.0000
6	.5000 1.0000	.6666 1.3333	.9666 1.9333	.8833 1.7666	.3750 .7500	.8833 1.7666	.9666 1.9333	.6666 1.3333	.5000 1.0000
7	.5000 1.0000	.6568 1.3166	.9916 1.9833	.8750 1.7500	.4583 .9166	.8166 1.6333	.9333 1.8666	.6666 1.3333	.5000 1.0000
8	.4583 .9166	.6583 1.3166	.9583 1.9166	.8416 1.6833	.4083 .8166	.7916 1.5833	.9416 1.8833	.6583 1.3166	.5000 1.0000
9	.4250 .8500	.6500 1.3000	.9416 1.8833	.8416 1.6833	.4333 .8667	.6333 1.2666	.8750 1.7500	.6500 1.3000	.4750 .9500
10	.5000 1.0000	.6416 1.2833	.9583 1.9166	.9916 1.9833	.5333 1.0666	.9000 1.8000	.9416 1.8833	.6583 1.3166	.4916 .9833
11	.4916 .9832	.6416 1.2833	.9166 1.8333	.6583 1.3166	.6250 1.2500	.7416 1.4833	.8833 1.7666	.6250 1.2500	.4916 .9833

SYMBOL/SECOND
BIT/SECOND

TABLE 2b: MEAN INFORMATION TRANSMISSION RATES

UNDER HIGH LOW HIGH CONDITION (SYMBOL/SEC. & BIT/SEC.)

SUBJECT	PRESENTATION RATE (SYMBOL/SECOND & BIT/SECOND)								
	2.00	1.33	1.00	.66	.50	.66	1.00	1.33	2.00
	4.00	2.67	2.00	1.33	1.0	1.33	2.00	2.67	4.00
1	.5583 1.1166	.5500 1.1000	.8083 1.6166	.6500 1.3000	.4916 .9832	.6416 1.2832	.8000 1.6000	.5166 1.0332	.4666 .9333
2	.5250 1.0500	1.0166 2.0333	.9333 1.8666	.6583 1.3166	.5000 1.0000	.6666 1.3333	.9666 1.9333	.9833 1.9666	.5750 1.1500
3	.4583 .9166	.8083 1.6166	.9750 1.9500	.6666 1.3333	.5000 1.0000	.6500 1.3000	.9583 1.9166	1.0166 2.0333	.4833 .9666
4	.3583 .7166	.8000 1.6000	.9333 1.8666	.6666 1.3333	.5000 1.0000	.6583 1.3166	.9666 1.9333	.9083 1.8166	.4500 .9000
5	.5583 1.1166	.7666 1.5333	.9416 1.8833	.6666 1.3333	.5000 1.0000	.6666 1.3333	.9750 1.9500	.9416 1.8833	.5083 1.0166
6	.5833 1.1666	.9250 1.8500	.9000 1.8000	.6250 1.2500	.5000 1.0000	.6583 1.3166	.9333 1.8666	1.0000 2.0000	.6500 1.3000
7	.5833 1.1666	.9166 1.8333	.9166 1.8333	.6500 1.3000	.5000 1.0000	.6583 1.3166	.9500 1.9000	.9416 1.8833	.6166 1.2333
8	.5000 1.0000	.5333 1.0666	.8666 1.7333	.6500 1.3000	.5000 1.0000	.6666 1.3333	.9333 1.8666	.6500 1.3000	.6500 1.3000
9	.4916 .9833	.9750 1.9500	.9833 1.9666	.6666 1.3333	.5000 1.0000	.6666 1.3333	.9750 1.9500	.9916 1.9833	.5583 1.1166

SYMBOL/SECOND

BIT/SECOND

Statistical analysis of data was as follows:

1) In order to determine the effect of different presentation rates, separate Friedman Two Way Analysis of Variance by Ranks was applied to data obtained under the Low High Low and High Low High conditions.

2) It had been hypothesized that the peak of the increasing rates would be higher than that of decreasing rates. Therefore, the Wilcoxon Matched Pairs Signed Ranks Test was applied to the average values of the increasing rates and decreasing rates under Low High Low condition. The increasing rates were from 2 sec./symbol to .5 sec./symbol and the decreasing rates were from .5 sec./symbol to 2 sec./symbol. The turning point was .5 sec./symbol (2.00 bit/sec.) and was not considered point of the ascending or descending sequence. The test was also applied to data obtained under High Low High conditions with the decreasing rates from .5 sec./symbol to 2 sec./symbol to .5 sec./symbol. The turning point was 2 sec./symbol (1 bit/sec.) and was not considered point of the ascending or descending sequence.

3) To determine if the data obtained under Low High Low and High Low High conditions were from the same population, the median test was selected.

III. RESULTS

The analysis of data showed the following results:

1) Figures 7 and 8 are graphs of transmission rates presented against the presentation rates.

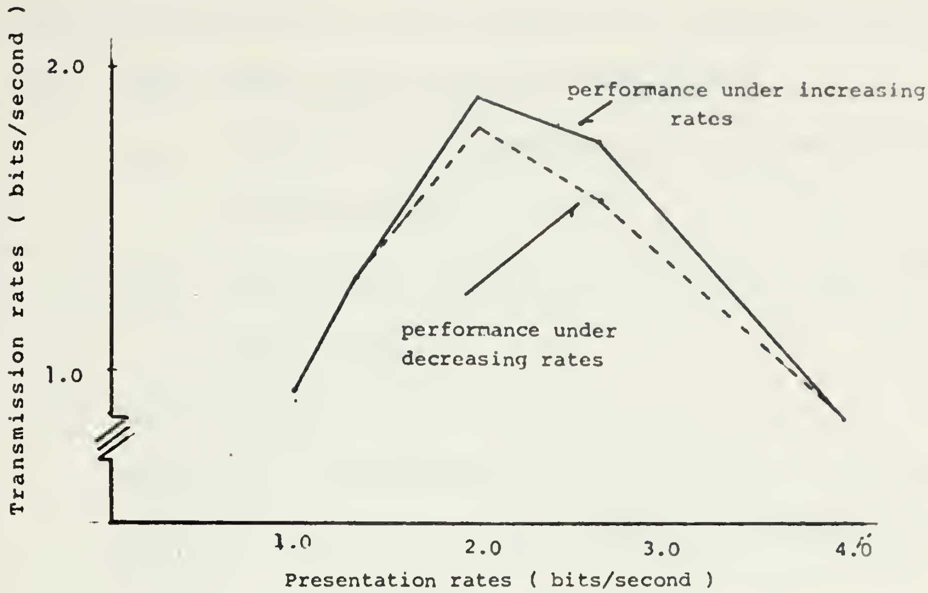

FIG. 7 : PERFORMANCE UNDER LOW HIGH LOW CONDITION.

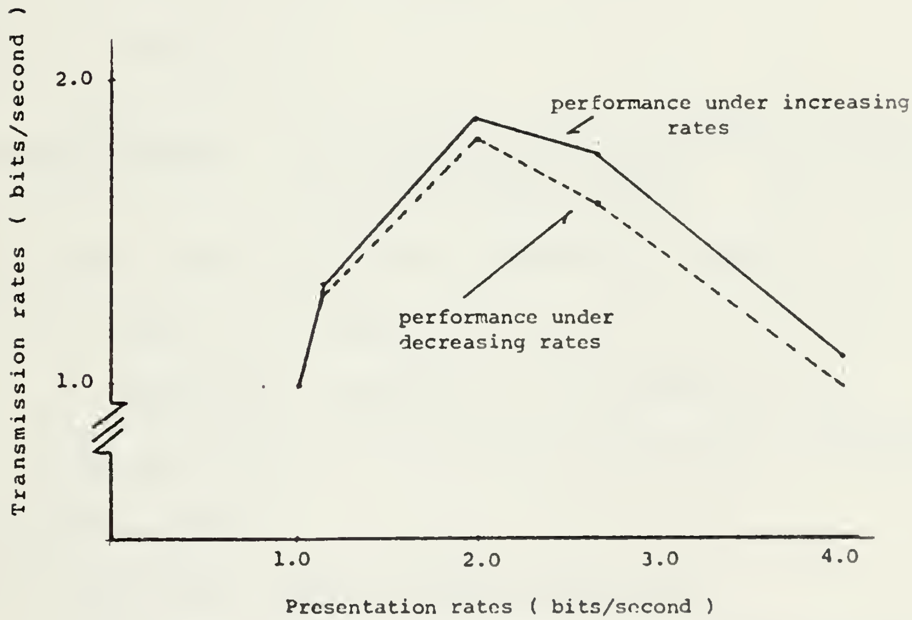

FIG. 8 : PERFORMANCE UNDER HIGH LOW HIGH CONDITION.

2) The Friedman Two Way Analysis of Variance by Ranks

a) Data under Low High Low condition

H_o: Different presentation rates have no differential effect

H_1: Different presentation rates have differential effect

Significant level: .10

Sampling distribution (see Table 3) is approximately chi square with degrees of freedom k-1.

$$\chi^2_r = \frac{12}{Nk(k+1)} \sum_{J=1}^{k} (R_J)^2 - 3\,N(k+1)$$

Where N = 11, k = 9

$$\chi^2_r = \frac{12}{(11)(9)(10)} \quad 400+2862.25+8372.25+6480.25+484+4096 +7140.25+2862.25+625 \quad -3(11)(10)=73.906$$

χ^2_r = 73.906 (df=8) has the probability under H_o less than .001 (p .001)

Decision: Reject H_o, in favor of H_1

The conclusion is that the scores were dependent on presentation rates.

b) Data under High Low High condition

H_o: Different presentation rates have no differential effect

H_1: Different presentation rates have differential effect

Significant level: .10

TABLE 3: RANKED PERFORMANCE OF ELEVEN SUBJECTS UNDER THE LOW HIGH LOW CONDITION

SUBJECT	RATE OF PRESENTATION (SECOND/SYMBOL)								
	2.0	1.5	1.0	.75	.50	.75	1.0	1.5	2.0
1	1	4.5	9	7	3	6	8	4.5	1.5
2	4	5	9	8	1	2.5	7	6	2.5
3	2	6	8	7	1	4	9	5	3
4	1	5	6	9	3	8	7	4	2
5	1	4.5	7	9	3	8	6	4.5	2
6	2.5	4.5	8.5	6.5	1	6.5	8.5	4.5	2.5
7	2.5	4	9	7	1	6	8	5	2.5
8	2	4.5	9	7	1	6	8	4.5	3
9	1	6.5	9	5	2	4	8	6.5	3
10	2	4	8	9	3	6	7	5	1
11	1	5	9	6	3	7	8	4	2
R_j	20	53.5	91.5	80.5	22	64	84.5	53.5	25

Sampling distribution (see Table 4) is approximately chi square with degrees of freedom k-1.

$$\chi_r^2 = \frac{12}{Nk(k+1)} \sum_{J=1}^{k} (R_J)^2 - 3\,N(k+1)$$

Where N = 9, k = 9

$$\chi_r^2 = \frac{12}{9(9)(10)} \quad 342.25+2916+4489+1764+240.25+2025+5256.25$$
$$+4249.25+625 \quad - 3(9)(10) = 55.15$$

$\chi_r^2 = 55.15$ with df = 8 has probability under H_o of less than .001 (p .001)

Decision: Reject H_o, in favor of H_1

The conclusion is that the scores were dependent on presentation rates.

3) The Wilcoxon Matched Pairs Signed Rank Test:

a) Data under Low High Low condition

H_o: The average transmission both in the increasing and the decreasing rates are the same.

H_1: The average transmission in the increasing rates is higher than that in the decreasing rates.

Significant level: .10

Test statistic: T = 2, N = 9 (see Table 5)

The value of T was so small that H_o can be rejected at level of significant .025.

Decision: Reject H_o in favor of H_1

The conclusion is that the transmission in the increasing rates is higher than that in the decreasing rates.

TABLE 4: RANKED PERFORMANCE OF NINE SUBJECTS UNDER THE HIGH LOW HIGH CONDITION

SUBJECT	PRESENTATION RATE (SECOND/SYMBOL)								
	.50	.75	1.0	1.5	2.0	1.5	1.0	.75	.50
1	5	4	9	7	2	6	8	3	1
2	2	9	6	4	1	5	7	8	3
3	1	6	8	5	3	4	7	9	2
4	1	6	8	5	3	4	9	7	2
5	3	6	7.5	4.5	1	4.5	9	7.5	2
6	2	7	6	3	1	5	8	9	4
7	2	6.5	6.5	4	1	5	9	8	3
8	1.5	3	8	5	1.5	7	9	5	5
9	1	6.5	8	4.5	2	4.5	6.5	9	3
R_j	18.5	54	67	42	15.5	45	72.2	65.5	25

TABLE 5:

THE AVERAGE TRANSMISSION
UNDER INCREASING AND DECREASING RATES

PAIR	INCREASING RATES	DECREASING RATES	d	RANK OF d	RANK OF LESS FREQUENT SIGN
1	1.4523	1.4250	.0273	3	
2	1.4625	1.2124	.2501	9	
3	1.3416	1.3125	.0291	4	
4	1.5750	1.5750	.0		
5	1.6125	1.5583	.0842	8	
6	1.5083	1.5083	.0		
7	1.5125	1.4583	.0542	7	
8	1.4583	1.4458	.0125	1	
9	1.3250	1.2750	.050	5	
10	1.5458	1.4958	.0500	5	
11	1.3541	1.3708	-.0167	-2	T=2

b.) Data under High Low High condition

H_o: The average transmission is the same in both increasing rates and decreasing rates

H_1: The average transmission in the increasing rates is higher than that in the decreasing rates

Significant level: .10

Test statistic: T = 4, N = 9 (See Table 6)

The value of T was so small that H_o can be rejected at level of significant .025.

Decision: Reject H_o in favor of H_1.

Conclusion is that the average transmission in the increasing rates is higher than that in the decreasing rates.

TABLE 6:

THE AVERAGE TRANSMISSION
UNDER DECREASING AND INCREASING RATES

PAIR	DECREASING RATES	INCREASING RATES	d	RANK OF d	RANK OF LESS FREQUENT SIGN
1	1.2833	1.2124	-.0709	-4	4
2	1.5667	1.5958	.0291	1	
3	1.4541	1.5541	.1000	6	
4	1.3791	1.4916	.1125	8	
5	1.4666	1.5458	.0792	5	
6	1.5166	1.6208	.1042	7	
7	1.5333	1.5833	.0500	3	
8	1.2749	1.4499	.1750	9	
9	1.5543	1.5958	.0375	2	T=4

4) Median Test

H_o: The Low High Low and High Low High groups are from a population with the same median (see Tables 7a & 7b).

H_1: The median of one population is different than that of the other.

Significant level: .10

TABLE 7a: ELEVEN MEDIANS IN INFORMATION TRANSMISSION UNDER LOW HIGH LOW CONDITION

SUBJECT	MEDIAN
1	1.3166
2	1.3000
3	1.3000
4	1.3000
5	1.3333
6	1.3333
7	1.3333
8	1.3166
9	1.2666
10	1.3166
11	1.2833

TABLE 7b: NINE MEDIANS IN INFORMATION TRANSMISSION UNDER HIGH LOW HIGH CONDITION

SUBJECT	MEDIAN
1	1.1166
2	1.3333
3	1.3333
4	1.3333
5	1.3333
6	1.3166
7	1.3166
8	1.3000
9	1.3333

COMBINED MEDIAN: 1.3166

Test statistic: Consider two cases

- Case #1 (see Table 7c); A + B = 11, C + D = 9 and C = 2. The value of C was greater than the value at the level of significance .10 (where C = 0) that H_o cannot be rejected.

  Decision: Cannot reject H_o

- Case #2 (see Table 7d); A + B = 11, C + D = 9 and C = 4. The value of C was greater than the value at the level of significance .10 (where C = 2).

  Decision: Cannot reject H_o

The conclusion is that the samples under both conditions were from the population with the same median.

TABLE 7c

	less than median	greater than or equal to median
LHL	A 5	B 6
HLH	C 2	D 7

TABLE 7d

	less than or equal to median	greater than median
LHL	A 8	B 3
HLH	C 4	D 5

IV. DISCUSSION AND CONCLUSION

Based upon the statistical analysis and the graphical representation of data, it was concluded that rate of information transmission depended upon the rate of information presentation. Thus, the data supported the hypotheses of the present study, namely:

1) The peak of performance in information transmission achieved for increasing rates was higher than that achieved for decreasing rates and,

2) The general shape of the curve remained the same under both conditions of Low High Low presentation rates and of High Low High presentation rates.

Cumming & Croft (1973), using auditory stimuli under Low High Low presentation rates, found the curve of performance in information transmission as shown in Figure 9. The general shape of the curve is similar with those obtained in this experiment. Specifically, performance under increasing

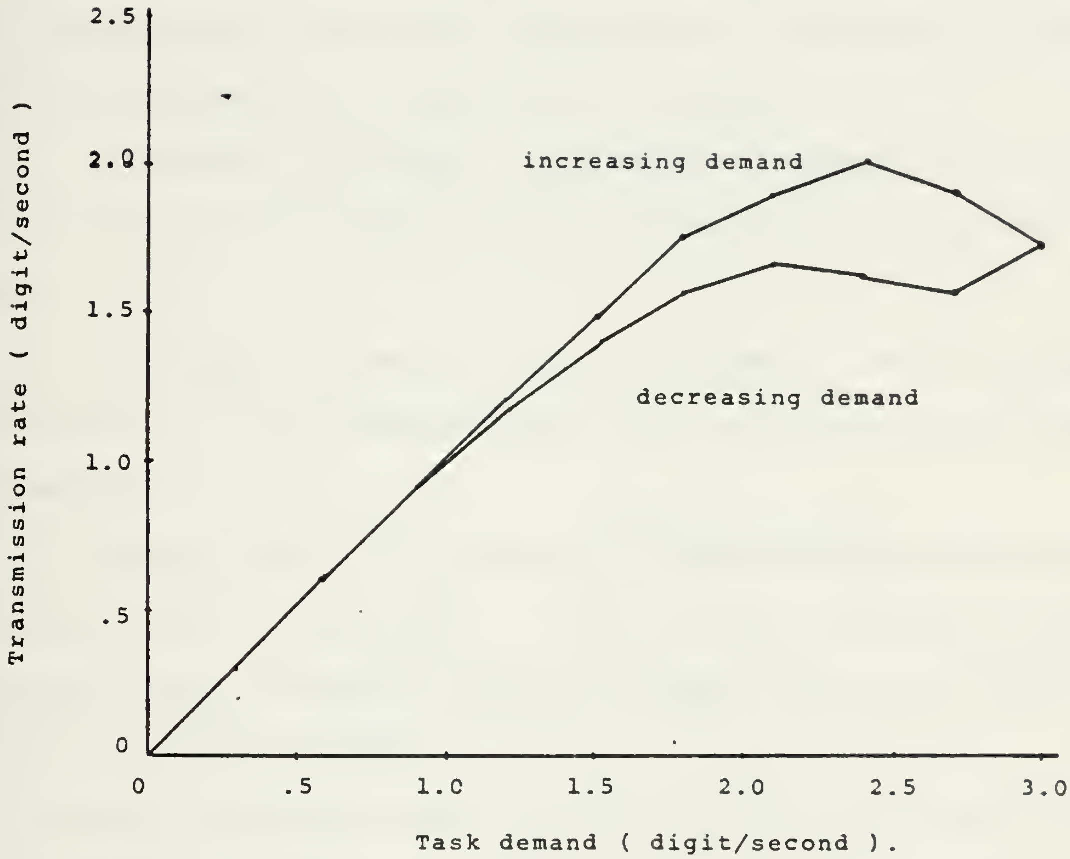

FIG. 9 : VARIATION OF PERFORMANCE (after Cumming & Croft,1973)

rates exceeded performance under decreasing rates (see Figures 10 and 11).

This experiment has demonstrated that the information transmission rate is a function of the information presentation rate. The relationship between performance in information transmission and demand expressed in the rate of information presentation is described as follows:

1) As demand increased, performance increased until the maximum level was reached, beyond which performance deteriorated.

2) As demand decreased, lower performance was observed and the peak of performance under the increasing rates was not reached.

3) Regardless of the series of demand (either from low to high to low or from high to low to high) the peak of performance under increasing demand is higher than that achieved under decreasing demand.

In the increasing demand case, it can be postulated that performance decrement after reaching the peak was due to information overload (arrival of more information that could be processed). In the decreasing demand, the optimum level of performance was lower due to the subject's expectancy set that the task will become easier.

The information analysis of this experiment clearly offers better understanding in human information processing, such as in the performance of military duty where man is viewed as processor of information.

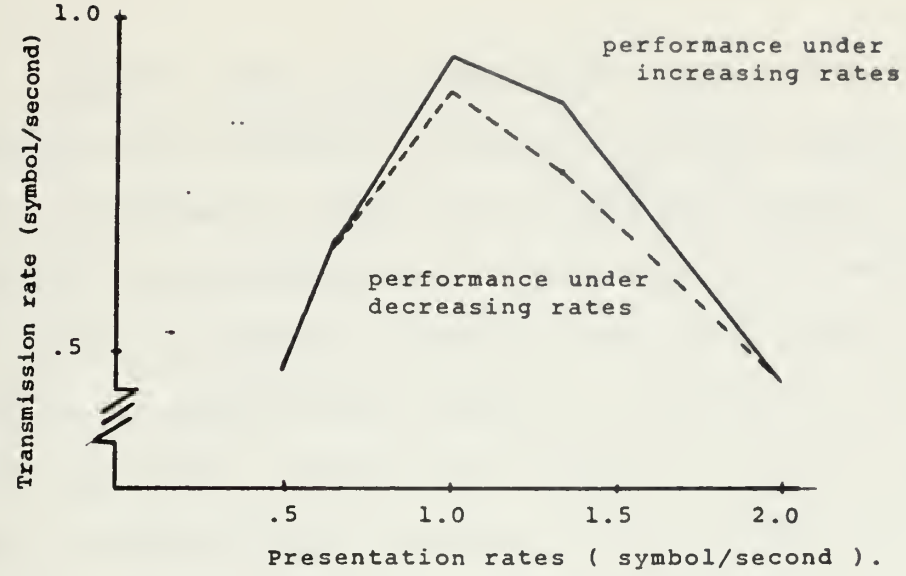

FIG.10 : PERFORMANCE UNDER LOW HIGH LOW CONDITION.

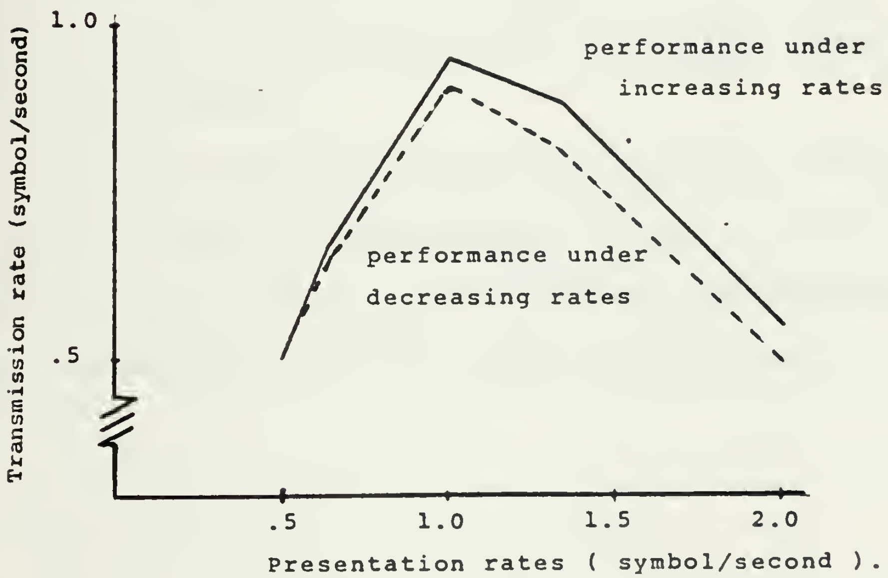

FIG.11 : PERFORMANCE UNDER HIGH LOW HIGH CONDITION

It appears from this study that the increasing demand stimulated the operator's expectation which resulted in better performance, whilst the decreasing demand gave the operator low expectancy and resulted in lower performance.

In the air defense situation, aircraft tracks are monitored by an observer who assigns an appropriate weapon to attack the enemy. When large numbers of the same type of threat aircrafts were observed, it was likely that the observer's performance would reach the optimum followed by performance decrement (monitoring randomly). At this stage, the optimal strategy would be the grouping of targets which would increase the level of performance. In the case of the smaller number of aircraft, selective monitoring will improve performance.

It is felt that the present information analysis will contribute to better understanding of man as an information processor in both military and civilian organizations (such as those responsible for air traffic monitoring and controlling).

APPENDIX A
INSTRUCTIONS TO THE SUBJECTS

The rater is a test of your information processing. Four different symbols, viz. cross, circle, triangle and diamond will appear automatically in a continuous random series in the viewing window. Each of the four response buttons below the viewing window corresponds to one of the four symbols. Your task is to respond to each symbol as it appears in the viewing window by pressing the corresponding correct button.

After a symbol is presented, you are to press the appropriate button. If you fail to respond within the time available a new symbol will be presented. The number of correct responses, incorrect responses and failure to respond will be recorded.

Try to respond rapidly, but as accurate as you can. Press only one button at a time, and give only one response to each symbol presented. If you press any two buttons simultaneously or give more than one response to any symbol, an error will be recorded. You will receive two practice trials to help you learn the correct button.

Remember that although the sequence of the symbols is completely random, runs of the same symbols may occur. Do not try to anticipate which symbol will appear next.

Place the thumb and forefinger of each hand on the response buttons. Maintain this position throughout each trial. We will begin with the practice trials.

Watch for the ready light. A trial begins three seconds later when the test light comes on. Begin responding when the first symbol appears and continue to respond until the test light goes off indicating the end of each trial. You will be given two practice trials consisting of 140 presentations. Do you have any questions?

(After the practice session was finished)

Now that you have learned the correct button for each symbol, be ready whenever the test light comes on and begin to respond to each symbol presented until the test light goes off. You will be informed when the first test series is completed.

APPENDIX B1

SUMMARY OF $\bar{X}$ VALUE UNDER LOW HIGH LOW CONDITION

SUBJECT	PRESENTATION RATE (SECOND/SYMBOL)								
	2.00	1.50	1.00	.75	.50	.75	1.00	1.50	2.00
1	29	39.5	56	49.5	30	48	54.5	39.5	29
2	30	39	54.5	52	23	29	47.5	40	29.5
3	26.5	40	51.5	43	21.5	33.5	56	39	29
4	28.5	39	56	65.5	30.5	64	57	38.5	29.5
5	29.5	40	58.5	65.5	35	59	58	40	30
6	30	40	58	53	22.5	53	58	40	30
7	30	39.5	59.5	52.5	27.5	49	56	40	30
8	27.5	39.5	57.5	50.5	24.5	47.5	56.5	39.5	30
9	25.5	39.	56.5	50.5	26	38	52.5	39	28.5
10	30	38.5	57.5	59.5	32	54	56.5	39.5	29.5
11	29.5	38.5	55	39.5	37.5	44.5	53	37.5	29.5

APPENDIX B2

SUMMARY OF $\bar{X}$ VALUE UNDER HIGH LOW HIGH CONDITION

SUBJECT	PRESENTATION RATE (SECOND/SYMBOL)								
	.50	.75	1.00	1.50	2.00	1.50	1.00	.75	.50
1	33.5	33	48.5	39	29.5	38.5	48	31	28
2	31.5	61	56	39.5	30	40	58	59	34.5
3	27.5	48.5	58.5	40	30	39	57.5	61	29
4	21.5	48	56	40	30	39.5	58	54.5	27
5	33.5	46	56.5	40	30	40	58.5	56.5	30.5
6	35	55.5	54	37.5	30	39.5	57	56.5	39
7	35	55	55	39	30	39.5	57	56.5	37
8	30	32	52	39	30	40	56	39	39
9	29.5	58.5	59	40	30	40	58.5	59.5	33.5

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